Tubular pinch effect of red blood cells at low Reynolds number in *in vitro* models of microvascular bifurcations

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Abstract

Introduction

The radial position of red blood cells (RBCs) is one of the factors affecting the phase separation at microvascular bifurcations. In our earlier study [1] we showed an inversion of the Zweifach-Fung effect and we hypothesized that it was due to a RBC depletion in the central region of the parent vessel. The aim of this study is to investigate *in vitro* the radial distribution of RBCs in a parent vessel of a microvascular bifurcation which could help to explain the observed inversion of the Zweifach-Fung effect.

Methods

The polydimethylsiloxane microdevice, fabricated with the standard process of soft-lithography, embeds a symmetric bifurcation (Fig.1a) with rectangular cross-section ($height = 8\mu$m, $width = W = 13\mu$m). We prepared a suspension of porcine RBCs at 5% of base hematocrit to reproduce blood density and viscosity, similarly to [1]. We performed the experiment in a pressure-controlled mode by setting a hydrostatic pressure difference between the fluid level in the reservoir and the outlet of the device equal to $\Delta P = 12cmH_2O$, which led to a Reynolds number of Re=0.008 in the parent vessel. A particle-tracking algorithm was used to analyse the image sequence, compute the RBC velocity and the particle coordinates in longitudinal and radial direction. Flux (RBCs/second) and line density (RBCs/m) profiles in function of the radial coordinate were derived from these data.

Results

We found cell-depleted regions close to the walls, in line with previous studies [2], and along the central axis of the channel (Fig.1b). Our results showed also two symmetric RBC-enriched regions (equilibrium positions) at $y* = y/[W/2] = \pm 0.5 - 0.6$, where the maximum line density was 3.3 times higher than in the center of the channel.

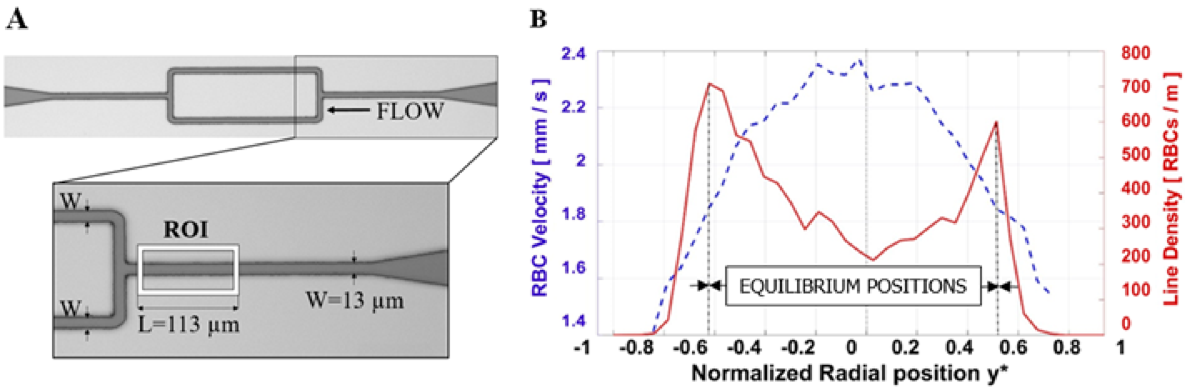

Fig.1: (**A**) Design of the microvascular bifurcation. A white frame highlights the region of interest (length=L, width=W). Images are acquired with a high-speed camera (frame rate=298 s^{-1}); (**B**) Red cell Velocity (dash line) and Line Density (solid line) profiles in function of the normalized radial position y*= y / [W/2], where y is the radial coordinate and W/2 is half width of the microchannel.

Fig. 1: (**A**):Design of the microvascular bifurcation. The region of interest for the experiment has been highlighted in white. Images are acquired with a high-speed camera ($frame\ rate = 298s^{-1}$); (**B**): Red Cell Velocity (dash line) and Line Density (solid line) profiles in function of the normalized radial position $y* = y/[W/2]$, where y is the radial coordinate and $W/2$ is half width of the microchannel.

Discussion

We reported for the first time, to the best of our knowledge, a tubular pinch effect [3] of deformable RBCs at physiological hematocrit and Reynolds number (Re<1) in channels with a width comparable to RBC size. Lima et al. [2] showed similar behaviour for wider channels and same levels of hematocrit; few experimental [4] and computational [5] studies reported tubular pinch effect for deformable RBCs but only for higher Reynolds numbers (Re>1). The observed phenomenon for low Reynolds and low haematocrit, could explain the inversion of the Zweifach-Fung effect and its consequences on RBC partition at microvascular bifurcations. These results may be of interest for other microfluidic applications.

Acknowledgments

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References

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